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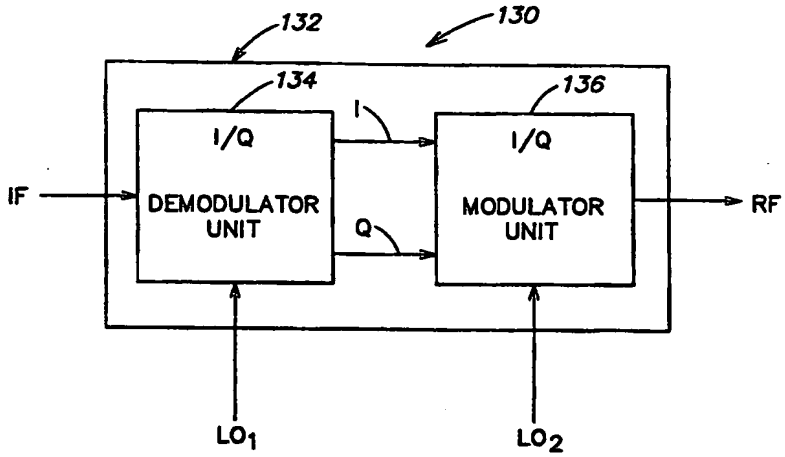
(54) Title: DIRECT CONVERSION UP-CONVERTER FOR BROADBAND WIRELESS ACCESS EQUIPMENT



(57) Abstract: A direct conversion up-converter provides direct up-conversion of a modulated broadband intermediate frequency ("IF") signal, which is on the order of 5 to 50 MHz, to a modulated radio frequency ("RF") signal, which is on the order of 70 MHz to 60 GHz. The direct up-conversion does not use super-heterodyne mixing. The direct conversion up-converter includes a demodulator unit to demodulate the modulated IF signal into a real baseband signal component ("I") and an imaginary baseband signal component ("Q"). Each basedband signal component I and Q is then amplified and passed through a bandpass filter to remove high frequency noise. The filtered baseband signal I and Q are then modulated by a modulator unit into a modulated RF signal. The demodulator unit performs the demodulation with an oscillation frequency corresponding to the modulation frequency of the modulated IF signal. The modulator unit performs the modulation with a second oscillator frequency which corresponds to a desired modulation frequency of the modulated RF signal. The demodulator unit and the modulator unit are formed from a plurality of integrated circuits disposed on a signal circuit board.

WO 01/67592 A2

DIRECT CONVERSION UP-CONVERTER FOR BROADBAND WIRELESS ACCESS EQUIPMENT

BACKGROUND OF THE INVENTION

The present invention relates to the art of up-conversion of a modulated communication signal. More particularly, the present invention relates to the art of up-conversion of a modulated intermediate frequency signal to a radio frequency signal which is suitable for wireless communication.

Electronic communication has enjoyed a rich history for over one-hundred years. Through experimentation, it has been discovered that certain electromagnetic frequencies transmit information with greater efficiency and less noise than other frequencies. These frequencies have been designated as the radio spectrum. The radio spectrum is part of the natural spectrum of electromagnetic radiation, and generally lies between frequency limits of 10×10^3 and 300×10^9 Hz. Of course, because the characteristics of electromagnetic radiation do not change abruptly, these limits are not sharply defined and may change, depending upon demands for changes in service and changes in technology.

The radio spectrum, which is available for electronic communication, is also subject to governmental regulation. International agreements within the International Telecommunications Union ("ITU") and the International Electrotechnical Commission ("IEC") provide administration of the limited spectrum which is available for radio communication. In the United States, administration of the available radio spectrum is provided by the Rules and Regulations of the Federal Communications Commission ("FCC"). The types of communication which find application within the radio spectrum include, among others, AM ("amplitude modulation") broadcasting, FM ("frequency modulation") broadcasting, television broadcasting, satellite broadcasting, and cellular communication.

To effectively utilize the available radio spectrum for communication, the information content from audio and visual signals must be transferred within a designated band. In the United States, for example, broad bands of frequencies are assigned as follows: medium frequency AM broadcasting between 525 and 1705 kHz (as of July 1990); high-frequency AM broadcasting between 2300 and 26,100 kHz; FM broadcasting between 88 and 108 MHz; and television broadcasting, four distinct bands between 54 and 806 MHz, which are subdivided into 68 channels. The advent of high definition television, direct broadcast satellite, mobile

communication service including cellular and cordless telephony, and multi-point distribution systems (known as "wireless cable") each require their own radio space, which is subject to constant revision and reallocation by governmental authorities. However, it becomes clear that modern communication requires flexibility in both technology and design in order to accommodate current needs and future changes.

For a more detailed review of point-to-multipoint communication and wireless modems, reference is made to co-pending patent application DYNAMIC ADAPTIVE MODULATION NEGOTIATION FOR POINT-TO-POINT TERRESTRIAL LINKS, the content of which being incorporated herein by reference.

In order to effectively utilize the available radio spectrum for communication, narrow band information such as audio and video information is usually modulated onto a carrier frequency within a designated frequency band. Therefore, in general, "modulation" is the modification of a high-frequency carrier signal to include information present in a relatively narrow bandwidth signal (which is designated as the modulating signal). Modulation is used because radio-wave propagation is more efficient at higher frequencies and smaller antennas can be used. Also, a larger bandwidth can be obtained at higher frequencies, thereby enabling multiple information-containing signals to be multiplexed onto a single carrier and sent simultaneously. Of course, after the modulated carrier signal is received, the signal must be demodulated to retrieve the information.

FIG. 1 (PRIOR ART) illustrates a common device for frequency modification, and historically the most commonly used device, in the form of a super-heterodyne frequency mixer or simply mixer. As illustrated, mixer 100 is a four quadrant multiplier, which multiplies a first sinusoidal input frequency f_1 by a second sinusoidal input frequency f_2 to produce an output $f_o = f_1 f_2$. Because each frequency represents a sinusoidal voltage, the output may be written as follows:

$$f_1 = A_1\cos(\omega_1 t) \qquad 1.1$$

$$f_2 = A_2\cos(\omega_2 t) \qquad 1.2$$

$$f_o = f_1 f_2 = A_1 A_2/2[\cos(\omega_1-\omega_2)t + \cos(\omega_1+\omega_2)t] \qquad 1.3$$

With reference to equation 1.3, when two signals of discrete frequencies are incident upon mixer 100, the mixer produces two outputs, or products. The frequency of one product is the sum of the input frequencies and the frequency of the other product is the difference of the input frequencies. This method of converting an input signal having a first frequency to an output signal of a second frequency is used in the majority of wireless communication devices today (i.e. cell phones, televisions, radios, etc.).

A major disadvantage of traditional mixing is that multiple output frequencies are produced by the mixer as a result of the frequency multiplication. The multiple output frequencies are due to the required use of non-linear devices in the fabrication of mixers. In fact, any non-linear device may serve as a mixer. It is the non-linearity itself that is required for the production of frequencies not present in the input. Understandably, mixers are therefore made from a variety of circuit elements such as diodes, BJTs, FETs, and even saturable reactors.

However, every mixer produces a desired output and an undesired output. It will be shown that, in fact, mixers produce many undesired output signals. These undesired outputs must be eliminated, or filtered, in order to meet regulatory and engineering design requirements. The ability to filter unwanted frequency products is ultimately limited by the overall tuning range of the system. The wider the tuning range, the greater the opportunity for unwanted frequency products to interfere with the desired output.

FIG. 2 (PRIOR ART) illustrates a mixer, represented by a nonlinear device 102 with the two input voltage sources 104 and 106 representing voltages $v_1(t)$ and $v_2(t)$ and having respective frequencies f_1 and f_2. If the device were perfectly linear (e.g. a wire or a resistor) the output would only contain frequencies f_1 and f_2. However, as set forth above, the purpose of a mixer is to change the frequency of the output, and accordingly a non-linear device is required.

The output current of any nonlinear device can be represented by the time domain Taylor series:

$$i_o(t) = I_o + \sum_{n=1}^{\infty} a_n v_i(t)^n \qquad 2.1$$

or

$$i_o(t) = I_o + a_1 v_i(t) + a_2 v_i(t)^2 + a_3 v_i(t)^3 + \ldots \quad 2.2$$

In the above equations, $v_i(t)$ is the voltage sum at the input nodes of the mixer and $i_o(t)$ is the output current. The input voltages can be represented by:

$$v_1(t) = A_1 \cos(\omega_1 t) \quad 2.3$$

$$v_2(t) = A_2 \cos(\omega_2 t) \quad 2.4$$

therefore

$$v_i(t) = A_1 \cos(\omega_1 t) + A_2 \cos(\omega_2 t) \quad 2.5$$

When $v_i(t)$ in equation 2.2 is replaced with equation 2.5 and appropriate trigonometry identities are applied, the output current is approximated by:

$$i_0(t) \approx \sum_i \sum_j [\cos[(i\omega_1 + j\omega_2)t] + \cos[(i\omega_1 - j\omega_2)t]] \quad 2.6$$

After inspecting equation 2.6, it can be seen that the mixer will produce a limitless number of unwanted products. Most of these products can be filtered using a bandpass filter, however based upon the choice of f_1 and f_2, there is a high probability that an unwanted product will fall within the passband of the filter and create interference. This interference can prevent equipment from operating as intended, cause equipment from being granted regulatory approval, and/or increase system cost.

Super-heterodyne mixing has evolved along with improvements in radio and television communication for over 50 years. Therefore, sophisticated techniques have been developed to increase signal strength and decrease noise. However, as a practical matter, super-heterodyne mixing is performed through a sequence of multiple stages, with each stage adding unwanted mixing products to the modulated signal. Thus, there is a problem in that signal clarity degrades in proportion to the number of mixing stages, and desired output frequency. Furthermore,

super-heterodyne mixing generally requires sophisticated filtering, which is particularly directed towards a specific desired output frequency.

As set forth above, in order to increase the tuning range using super-heterodyne mixing, additional mixing stages are used. Of course, there are other noise sources present in the output signal in addition to the unwanted mixing products. A predominant noise source is the phase noise of the local oscillators. The total phase noise power is the sum of the phase noise from each local oscillator. As the number of mixing stages increases, the phase noise performance degrades. Thus, a reduction in phase noise can be achieved by minimizing the number of mixing stages.

Another disadvantage of super-heterodyne mixing relates to system cost. The increased number of stages required in super-heterodyne mixing increases price and consumes board area. Thus, super-heterodyne mixing requires a larger circuit board area.

A more detailed review of super-heterodyne mixing may be found from J. Smith, Modern Communication Circuits, McGraw-Hill, Inc., ch. 12, pp. 455-475, and H.L. Krauss et al., Solid State Radio Engineering, ch. 7, pp. 188-196.

It is anticipated that cable modems will become an important means for conveying information through electronic communication. Cable modems take advantage of existing deployment of capital in the form of the cable television system infrastructure.

A cable modem is a device that negotiates incoming and outgoing data signals between a cable TV operator and a personal or business computer, or television set. Cable modems are currently standardized as CableLabs Certified Cable Modems to comply with DOCSIS ("Data Over Cable Service Interface Specifications"). Cable Television Laboratories ("CableLabs") is an industry standards organization that is responsible for certifying that cable modems are DOCSIS compliant.

DOCSIS 1.0 was ratified by the International Telecommunication Union ("ITU") in March of 1998. As DOCSIS continues to evolve to newer versions, existing modems are anticipated to be upgraded by changing programming in the cable modem's EEPROM memory. DOCSIS-compliant cable modems are currently being integrated into set-top boxes for use with television sets. DOCSIS is anticipated to converge with the high definition television ("HDTV") standard, with the set-top box itself following a standard known as OpenCable.

DOCSIS specifies modulation schemes and protocols for exchanging bidirectional signals over cable. DOCSIS currently supports downstream-to-the-user data rates up to 27 Mbps

(megabits per second). Since this data rate is shared by a number of users and because many cable operators will be limited by a T-1 connection to the Internet, the actual downstream data rate to an individual business or home is anticipated to be on the order of 1.5 to 3 Mbps.

As a method for conveying the above bit rates over cable modems, a modulated signal is output on the order of 5 to 50 MHz. Currently, there exists an upper frequency limit for communicating digital information over cable modems due to standard television communication between 50 and 860 MHz, as set forth above.

Unfortunately, the communication band of 5 to 50 MHz for transmission of information via a cable modem is not suitable for wireless, radio frequency ("RF") communication. RF frequencies for the transmission of modulated information are on the order of 70 MHz to 60 GHz. Currently, broadband data RF communication of modulated digital information is provided on the order of 2 to 30 GHz.

Accordingly, there is a need in the art for efficient up-conversion of modulated digital information from a frequency of 5 to 50 MHz to a frequency on the order of 3 GHz. There is a further need in the art for an efficient up-conversion of a modulated digital signal without the added complexities and noise introduced by super-heterodyne mixing. Furthermore, there is a need in the art for up-conversion of a modulated intermediate frequency carrier signal without unnecessary limitation of the tuning range. The limited tuning range available from super-heterodyne mixing results from the need to filter unwanted, out of band mixing products, and to prevent formation of unwanted, in-band mixing products. There is also a need to provide a broad tuning range during up-conversion of an intermediate-frequency ("IF") signal while reducing the need for complex, i.e. expensive, filters. Of course, a limited tuning range and a need for complex filters directly result from the inherent limitations in super-heterodyne mixing.

BRIEF SUMMARY OF THE INVENTION

It is therefore an object of the present invention to solve the above-mentioned problems associated with up-conversion of a modulated digital signal.

It is a further object of the invention to up-convert an intermediate frequency ("IF") signal which is on the order of 5 to 50 MHz, to a modulated radio frequency ("RF") signal, which is on the order of 1 to 6 GHz, without the use of super-heterodyne mixing.

It is an even further object of the invention to demodulate an IF signal into real and imaginary baseband components, known respectively as ("I") and ("Q"), and then to remodulate

the baseband signals to an RF signal, which is compatible with any quadrature amplitude modulation ("QAM") carrier.

It is still a further object of the present invention to reduce the requirements for filtering during up-conversion of a modulated IF signal to a modulated RF signal over a wide tuning range while minimizing the introduction of undesirable mixing products.

It is a further object of the invention to eliminate the disadvantages associated with super-heterodyne mixing during up-conversion of a modulated IF signal, while improving phase noise performance, reducing the number of required system components, reducing system cost, and conserving circuit board area.

Objects of the present invention are achieved by an up-converter to up-convert a modulated broadband intermediate frequency signal into a modulated broadband radio frequency signal, comprising a demodulator unit to demodulate the broadband intermediate frequency signal into a real signal component and an imaginary signal component; and a modulator unit to modulate the real signal component and the imaginary signal component into a modulated broadband radio frequency signal. The demodulator unit performs the demodulation by using a first oscillator frequency corresponding to the modulation frequency of the modulated broadband intermediate frequency signal, and the modulator unit performs the modulation by using a second oscillator frequency corresponding to a desired modulation frequency of the modulated broadband radio frequency signal. The intermediate frequency signal is an analog signal that carries digitally encoded information at a frequency between 5 to 70 MHz. The radio frequency signal is an analog signal that carries digitally encoded information at a frequency over 1 GHz.

Further objects of the present invention are achieved by an up-converter to up-convert a modulated broadband intermediate frequency signal into a modulated broadband radio frequency signal, comprising a demodulator unit to demodulate the broadband intermediate frequency signal into a real signal component and an imaginary signal component; a reconstruction filter unit to individually attenuate high order frequencies from each of the real signal component and the imaginary signal component, to produce an attenuated real signal component and an attenuated imaginary signal component; and a modulator unit to modulate the attenuated real signal component and the attenuated imaginary signal component into a modulated broadband radio frequency signal.

Even further objects of the present invention are achieved by a method of up-converting a modulated broadband intermediate frequency signal into a modulated broadband radio frequency

signal, comprising demodulating the broadband intermediate frequency signal into a real signal component and an imaginary signal component; and modulating the real signal component and the imaginary signal component into a modulated broadband radio frequency signal.

Moreover, objects of the present invention are achieved by an up-converter to up-convert a modulated broadband intermediate frequency signal into a modulated broadband radio frequency signal, the up-converter being comprised of a plurality of integrated circuits disposed on a single circuit board, the up-converter comprising a power splitter to split the received input IF signal into a first split signal and a second split signal; a first mixer to demodulate the first split signal with a demodulation oscillation signal having the same frequency as a carrier frequency in the received IF signal, and to output the result as a real signal component; a phase shifter to receive the demodulation oscillation signal and to shift the frequency 90°; a second mixer to demodulate the second split signal with the phase shifted demodulation oscillation signal, and to output the result as the imaginary signal component; a reconstruction filter unit to individually attenuate high order frequencies from each of the real signal component and the imaginary signal component, to produce an attenuated real signal component and an attenuated imaginary signal component; a third mixer to modulate the attenuated real signal component with a received modulation oscillation signal having the same frequency as the modulated radio frequency signal; a phase shifter to receive the modulation oscillation signal and to shift the frequency 90°; a fourth mixer to modulate the attenuated imaginary signal component with the phase shifted modulation oscillation signal; and a power combiner to combine the modulated real signal component with the modulated imaginary signal component to produce the modulated radio frequency signal.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects and advantages of the present invention will become apparent and more readily appreciated from the following description of the preferred embodiments, taken in conjunction with the accompanying drawings of which:

FIG. 1 (PRIOR ART) is schematic block diagram of a mixer used for super-heterodyne mixing.

FIG. 2 (PRIOR ART) is a schematic block diagram of the combination of two sinusoidal voltage signals across a non-linear device to produce a sinusoidal current output.

FIG. 3 is constellation of data points used in quadrature-phase-shift-keying ("QPSK") mixing.

FIG. 4 is a constellation of data points used in QAM-16 mixing.

FIG. 5 is a schematic block diagram of a QAM modulator for producing a QAM signal suitable for transmission by way of a cable modem.

FIG. 6a (PRIOR ART) is a schematic illustration of up-conversion of an IF signal to a BWA frequency signal using super-heterodyne mixing.

FIG. 6b (PRIOR ART) is a schematic illustration of up-conversion of an IF signal to a BWA frequency signal using a plurality of mixing stages.

FIG. 7 is a block diagram of a direct conversion up-converter for up-conversion of a modulated broadband IF signal to a modulated broadband RF signal according to a preferred embodiment of the present invention.

FIG. 8 is a block diagram of an up-converter according to a second embodiment of the present invention.

FIG. 9 is a block diagram of an up-converter optimized for broadband wireless access equipment, according to a third embodiment of the present invention.

FIG. 10 is a circuit diagram of a Gilbert mixer circuit according to an embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference will now be made in detail to the preferred embodiments of the present invention, examples of which are illustrated in the accompanying drawings, wherein like reference numerals refer to like elements throughout.

Turning now to the figures and in particular FIG. 3, a brief review of quadrature amplitude modulation ("QAM") signal theory is given for practice in combination with the present invention. In accordance with the principals of digital multi-level signaling, a digital input having more than two modulation levels is allowed. Multi-level signaling may be generated from a serial binary input stream using a digital-to-analog converter ("DAC"). Thus, for 2-bit digital to analog conversion, i.e. $\ell = 2$, the number of discrete levels, i.e. symbols, in a corresponding multi-level signal is represented as

$$M = 2^{\ell} = 2^2 = 4 \qquad 3.1$$

Thus, the symbol rate, i.e. baud rate, of a corresponding multi-level signal may be represented by

$$D = R / \ell = \tfrac{1}{2} R \qquad 3.2$$

where $R = 1 / T_b$ bits/s.

Accordingly, for a transmitter having four levels of modulation, i.e. a modulation scheme denoted as M = 4, M-ary phase-shift keying ("MPSK") is generated. The case when M = 4 is designated by convention as quadrature-phase-shift-keying ("QPSK").

FIG. 3 represents a constellation plot of permitted values of the complex envelope $g(t) = A_c e^{j\theta(t)}$ which has a combination of four points, designated respectively at 45°, 135°, 225°, and 315° for each value of g. The illustrated constellation has one amplitude state, and four discrete phase states, and is indicated as QPSK (quadrature-phase-shift-keying) or QAM-4.

Of course, the general form of a QAM signal is given by

$$s(t) = x(t)\cos(w_c t) - y(t)\cos(w_c t) \qquad 3.3$$

where,

$$g(t) = x(t) + jy(t) = A_c e^{j\theta(t)} \qquad 3.4$$

In other words, FIG. 3 represents both polar and rectangular coordinate representations of the signal information. According to the polar coordinate model, amplitude (which would correspond to the distance of the point from axis center) does not vary and is therefore represented as unity. As illustrated, two bits are grouped together for transmission, and are represented by a phase shift θ_i, in the signal. Historically, modems operating on the order of 600 to 4800 bits/s used this type of multi-bit phase shift keying modulation, i.e. QPSK.

Of course, the amplitude of a signal may also be modulated along with the phase. Accordingly, one of the more frequently used forms of modulation combines phase modulation with amplitude modulation. QAM-16 allows four bits to be represented by one amplitude and one phase change. For example, if a modem varies its signal 2400 times a second and each signal represents four bits, then the modem has a data rate of 9600 bits/s.

FIG. 4 illustrates a QAM-16 (M = 16) constellation in which 12 values of phase and 3 values of amplitude are employed to produce 16 possible signal states. The Consultative Committee for International Telephone and Telegraph ("CCITT") has adopted a standard of V.29 to implement a QAM-16 architecture. According to V.29, a 1700 Hz carrier is varied in both phase change and amplitude change, thereby resulting in 16 combinations of 8 phase signals and 4 amplitudes.

Of course, the number of discrete states per axis does not have a theoretical limit. Thus, for values of $M = 2^{\ell}$ with $\ell > 4$, (i.e. M = 32, 64 or 256) the amount of information represented by phase and amplitude may drastically increase, and be represented by corresponding constellations of 64 points or greater. The choice of a desired center frequency f_c is typically on the order of 5 to 70 MHz. The choice for this output frequency is based upon a number of factors, with a primary reason being the designated frequency range for cable modems. Additional information regarding quadrature amplitude modulation may be found in L.W. Couch, Digital and Analog Communication Systems, sec. 5-10, pp. 345-351.

FIG. 5 illustrates a QAM modulator 110 for producing a QAM signal suitable for transmission by way of a cable modem. As illustrated, QAM modulator 110 receives a serial digital input signal d(t) having an associated data rate of R bits/s. The serial digital input signal d(t) is then converted into two bits by way of 2-bit serial-to-parallel converter 112. The serial-to-parallel converter 112 then outputs two bit signals, respectively represented as $d_1(t)$ and $d_2(t)$, each having a corresponding bit rate of R/2. Each signal $d_1(t)$ and $d_2(t)$ is then subjected to digital-to-analog conversion by respective DACs 114 and 116. The analog signals, x(t) and y(t) are then up-converted to a desired IF ("intermediate frequency"), which is on the order of 5 to 50 MHz, by way of respective mixers 118 and 120. Each of mixers 118 and 120 mixes the respective signals x(t) and y(t) with an appropriate oscillation frequency f_c, which is supplied by local oscillator 122. The oscillation signal output from local oscillator 122 is shifted 90° by phase shifter 124 before being input to mixer 120. The outputs of mixers 118 and 120 are then

combined by power summation unit 126, to arrive at output s(t). Modulated IF ("intermediate frequency") signal s(t) is on the order of 5 to 70 MHz.

When modulated IF signal s(t) is desired to be transmitted at a higher frequency, the signal is traditionally up-converted using super-heterodyne mixing. Upconversion is desirable for transmission of the information content over spectrum allocations for broadband wireless access ("BWA"). Currently, two predominant spectrum allocations for BWA are designated as Multichannel Multipoint Distribution Service ("MMDS"), which is designated as 2.5 - 2.68 GHz, and Local Multipoint Distribution Service ("LMDS"), which is designated as 27.5 - 31.3 GHz. Therefore, to utilize the available broadband allocations, some form of upconversion is required.

FIG. 6a (PRIOR ART) schematically illustrates upconversion of an IF signal s(t) (which is on the order of 5 to 70 MHz) to a BWA frequency (which is on the order of 2.5 to 32 GHz) using the super-heterodyne mixer 100 of FIG. 1 (PRIOR ART). In actuality, upconversion from the above IF signal to the above BWA signal requires multiple mixing steps. Currently, super-heterodyne mixing provides a limit to the amount of frequency conversion which may be possible during a single mixing step due to the introduction of unwanted mixing products and spurious noise signals. Accordingly, FIG. 6b (PRIOR ART) more accurately represents upconversion to the required BWA signal frequency by using a plurality of mixing stages 100n and a plurality of local oscillation frequencies fc_n, which are output from corresponding oscillators (not shown). Of course, the use of multiple mixing stages 100n necessitates the use of multiple filters. By reference to the Taylor Series set forth above with regard to equations 2.1, 2.2 and 2.6, it is easily observed that a number of undesirable mixing products and noise elements are introduced through the operation of super-heterodyne mixing.

FIG. 7 illustrates a direct conversion up-converter 130 for upconversion of a modulated broadband intermediate frequency ("IF") signal to a modulated broadband radio frequency ("RF") signal, without the introduction of super-heterodyne mixing. According to a preferred embodiment of the present invention, input signal IF is a quadrature amplitude modulated ("QAM") signal. According to an alternate embodiment of the present invention, input signal IF is an amplitude modulated signal, a frequency modulated signal, a phase modulated signal, or subject to another form of modulation which includes a modulated signal and carrier signal, such as a combined modulation technique. Of course, input signal IF itself is an analog signal that may carry analog encoded information or digitally encoded information. According to a preferred embodiment of the present invention, the input IF signal is an analog signal that carries

digitally encoded information at a frequency between 5 to 70 MHz, such as that used for cable modems.

According to an embodiment of the present invention, up-converter 130 is packaged as a single integrated circuit 132. According to an alternate embodiment of the present invention, up-converter 130 includes a plurality of integrated circuits which are preferably packaged on a single circuit board. Of course, it is anticipated that up-converter 130 may be combined with a plurality of additional circuit elements, such as amplifiers, filters, line level converters, etc. for operation, the details of which being subject to change based upon the particular application, and thus being suitably omitted.

FIG. 7 illustrates up-converter 132 as including an I/Q demodulator unit 134 and an I/Q modulator unit 136. As illustrated, demodulator unit 134 receives modulated signal IF as an input. Demodulator unit 134 then demodulates an IF signal into real baseband component "I" and imaginary baseband component "Q" in response to local oscillator signal LO_1. The local oscillator signal LO_1 is matched to the carrier signal of modulated signal IF. Both signals I and Q are non-modulated baseband signals. Signals I and Q are preferably on the order from greater than 0Hz to 10 MHz, and are generally on the order of 1/2 the bandwidth of the IF signal.

Non-modulated baseband signals I and Q are then modulated with I/Q modulator unit 136 at a frequency determined in response to second local oscillator LO_2. The frequency of LO_2 determines the requisite output RF frequency. According to a preferred embodiment of the present invention, the output frequency RF is on the order of 70 MHz to 6 GHz. I/Q modulator unit 136 has the ability to modulate the individual I and Q signals at the requisite frequency in a single stage because all required information to protect signal integrity is already contained in the I and Q signals. According to a preferred embodiment of the present invention, I/Q modulator unit 136 provides a single mixing operation without introducing unwanted mixing products, as in super-heterodyne mixing. Of course, local oscillator signal LO_2 may be set to any desirable frequency, on the order of 70 MHz to 6 GHz, to provide direct conversion to the required frequency. This is preferable over super-heterodyne mixing, which requires additional filtering components optimized for a desired output carrier frequency. The present invention provides control over the desired output carrier frequency without the need for introduction of frequency dependent filtering components.

FIG. 8 illustrates an up-converter 140 according to a second embodiment of the present invention. As illustrated, input signal IF is a modulated intermediate frequency signal, which is

input into up-converter 140, then into demodulator unit 142. Input signal IF is then input into power splitter 144 and thereby split into two equal signals IF_1, and IF_2. Signal IF_1 is then received by multiplier 146. The local oscillator signal LO_1 is input into demodulator unit 142 through quadrature phase shifter 148.

As illustrated, local oscillator signal LO_1 is not subjected to a phase shift by quadrature phase shifter 148 and passes directly to multiplier 146. Local oscillator signal LO_1 is set to be the same frequency as the carrier frequency for input signal IF. Upon multiplication by multiplier 146, the carrier frequency is removed from IF_1 and the resulting signal is denoted as "I", i.e. the real portion of the baseband signal as shown in equation 3.4.

On the other hand, signal IF_2 is received by multiplier 150. Likewise, local oscillator signal LO_1 is input to demodulator unit 142 through quadrature phase shifter 148. However, local oscillator signal LO_1 is now subjected to a phase shift of 90° by quadrature phase shifter 148 before passing to multiplier 150. Local oscillator signal LO_1 is, of course, set to be the same frequency as the carrier frequency for input signal IF. Upon multiplication by multiplier 150, the carrier frequency is removed from IF_2 and the resulting signal is the imaginary baseband signal Q.

Real and imaginary baseband signals I and Q are then received by modulator unit 152 for modulation and recombination. As illustrated, real baseband signal I is directly multiplied by local oscillator signal LO_2 by way of multiplier 154. Of course, local oscillator signal LO_2 first passes through phase shifter 156, however, because I is the real baseband component, no phase shift is required.

On the other hand, imaginary baseband signal Q is received by multiplier 158. In this case, local oscillator signal LO_2 is phase shifted 90° by phase shifter 156 before being output to multiplier 158. As set forth above, the local oscillator signal LO_2 is, of course, set to be the desired carrier modulation frequency. Upon multiplication by multiplier 158, the carrier signal is added. The real output signal from multiplier 154 is then power combined with the imaginary output from multiplier 158 by way of power combiner 160. Power combiner 158 then outputs the modulated combined signal as output signal RF. Of course, according to an embodiment of the present invention, oscillator signals LO_1, and LO_2 may be provided from a single oscillator which is provided either on chip, or on-circuit, with additional circuitry provided to divide the LO_1 (having a lower frequency) from LO_2 (having a higher frequency).

In accordance with the second embodiment of the present invention set forth above, a desirable output frequency RF on the order of 70 MHz to 6 GHz is provided without requiring super-heterodyne mixing. Thus, greater control over the tuning range of the output carrier frequency is provided without the need for additional filtering components, which are optimized for a desired output carrier frequency.

FIG. 9 illustrates a direct conversion up-converter 170 optimized for broadband wireless access equipment, according to a third embodiment of the present invention. As illustrated, up-converter 170 includes three units, namely I/Q demodulator unit 172, reconstruction filter unit 174, and I/Q modulator unit 176.

I/Q demodulator unit 172 receives input signal IF, which is a modulated intermediate frequency signal. Input signal IF is then input into power splitter 178 and thereby split into two equal signals. One signal is then received by multiplier 180. Local oscillator 179 outputs demodulation oscillator signal f_i, which is then input into demodulator unit 172 through frequency divider 182 and phase shifter 184. As illustrated, the demodulation oscillator signal is not subjected to a phase shift by phase shifter 184 and passes to multiplier 180. Demodulation oscillator signal f_i is set to be twice the frequency of the carrier frequency of input signal IF, such that the signal is identical upon division by power splitter 178. Upon multiplication by multiplier 180, the carrier frequency is removed and the resulting signal is the real baseband signal I.

On the other hand, a second signal outputted by power splitter 178 is received by multiplier 186. Likewise, local oscillator signal f_i is input to demodulator unit 172 through frequency divider 182 and phase shifter 184. However, the signal is now subjected to a phase shift of 90° by phase shifter 184 before passing to multiplier 186. Demodulation oscillator signal f_i is, of course, set to be twice the frequency as the carrier frequency of input signal IF. Upon multiplication by multiplier 186, the carrier frequency is removed from the signal and the resulting signal is the imaginary baseband signal Q.

Real and imaginary baseband signals I and Q are then received by reconstruction filter 174. Reconstruction filter 174 provides signal amplification to each of the I and Q baseband components by way of corresponding amplifiers 188 and 190. Likewise, each of the baseband signals I and Q are then subject to filtering by way of low pass filters 192 and 194. Low pass

filters 192 and 194 each progressively attenuate high frequency signals, at a frequency which corresponds to 1/2 of the bandwidth of the originally inputted IF signal.

The low pass filters discriminate other spurious noise and the unwanted image created as a result of the demodulation process. After an analytical inspection of the demodulation process, it can be shown that a higher order "demodulation image" is created, which must then be filtered.

The modified baseband signals I* and Q* are then received by I/Q modulator unit 176. Modulator unit 176 is provided for modulation and recombination of the real and imaginary baseband signals I* and Q*.

As illustrated, local oscillator 204 outputs local oscillation signal f_o. Real baseband signal I* is then directly multiplied by local oscillator signal f_o by way of multiplier 195. Of course, local oscillator signal f_o first passes through phase shifter 198, however, because I is the real baseband component, no phase shift is required, i.e. a phase shift of 0° is added.

On the other hand, imaginary baseband signal Q* is received by multiplier 196. In this case, local oscillator signal f_o is phase shifted by 90° by way of phase shifter 198 before being output to multiplier 196. As set forth above, the local oscillator signal f_o is, of course, set to be the desired carrier modulation frequency. Upon multiplication by multiplier 196, the carrier signal is added to imaginary baseband signal Q*.

Next, the real output signal from multiplier 195 is power combined with the imaginary output from multiplier 196 by way of power summation unit 200. The combined signal is then amplified by amplifier 202 and output as f_o.

In accordance with the second embodiment of the present invention, set forth above, a desirable output frequency RF on the order of 70 MHz to 6 GHz is provided without requiring super-heterodyne mixing. Furthermore, greater control over the output carrier frequency is provided because the need for additional filtering components, which are optimized for a desired output carrier frequency, are not required.

FIG. 10 illustrates a Gilbert mixer circuit 210 according to a preferred embodiment of the present invention. A Gilbert mixer may be used in demodulation mode or in modulation mode. When Gilbert mixer circuit 210 is used in demodulation mode, I/Q INPUT A and I/Q INPUT B are tied together, and the tied inputs receive modulated input IF signal. After the IF signal is received at both points I/Q INPUT A and I/Q INPUT B, the signal drives the lower differential pair of transistors, respectively indicated as transistors 211 and 212. Upper transistors 214 and

216 are driven by LOCAL OSCILLATOR SIGNAL LO/2+ while upper transistors 218 and 220 are driven by LOCAL OSCILLATOR SIGNAL LO/2-. By convention, the signals "+" and "-" indicate that the received LO signals are 90° out of phase. The LO signals are represented as "LO/2" to indicate that the frequency must be at least twice the frequency of the IF signal received at ports I/Q INPUT A and I/Q INPUT B.

Due to economy of design, the frequency divider unit 182 (FIG. 9) in combination with phase shifter 184 (FIG. 9) is a digital divider in the form of a flip-flop which splits a received LO SIGNAL into two quadrature waveforms LO/2+ and LO/2- (separated by 90°) while dividing the frequency in two. Of course, according to another embodiment of the present invention, frequency divider unit 182 and phase shifter 184 may be comprised of two separate circuit elements as particularly illustrated in FIG. 9.

In view of the above, when Gilbert cell mixer 210 is used in demodulation mode, the signals IF+ and IF- indicate the I and Q baseband signals output from I/Q demodulator unit 172 of FIG. 9. Of course, the designations " + " and " - " indicate that the output IF signals (which represent the I and Q output signals from I/Q demodulator unit 172) are 90° out of phase.

One skilled in the art may readily understand that Gilbert mixer circuit 210 may operate in modulation mode for use as multipliers 195 and 196 in I/Q modulator unit 176 of FIG. 9.

Although a few preferred embodiments of the present invention have been shown and described, it will be appreciated by those skilled in the art that changes may be made in these embodiments without departing from the principles and spirit of the invention, the scope of which is defined in the claims and their equivalents.

CLAIMS

What is claimed is:

1. An up-converter to up-convert a modulated broadband intermediate frequency signal into a modulated broadband radio frequency signal, comprising:

a demodulator unit to demodulate the broadband intermediate frequency signal into a real signal component and an imaginary signal component; and

a modulator unit to modulate the real signal component and the imaginary signal component into a modulated broadband radio frequency signal.

2. The up-converter according to claim 1, wherein the demodulator unit performs the demodulation by using a first oscillator frequency which corresponds to the modulation frequency of the modulated broadband intermediate frequency signal.

3. The up-converter according to claim 2, wherein the modulator unit performs the modulation by using a second oscillator frequency which corresponds to a desired modulation frequency of the modulated broadband radio frequency signal.

4. The up-converter according to claim 1, wherein the modulator unit performs the modulation by using an oscillator frequency which corresponds to a desired modulation frequency of the modulated broadband radio frequency signal.

5. The up-converter according to claim 1, wherein the demodulator unit and the modulator unit are packaged as a single integrated circuit.

6. The up-converter according to claim 1, wherein the demodulator unit and the modulator unit are comprised of a plurality of integrated circuits which are disposed on a single circuit board.

7. The up-converter according to claim 1, wherein the input IF signal is an analog signal that carries digitally encoded information at a frequency between 5 to 70 MHz.

8. The up-converter according to claim 7, wherein the input IF signal is a quadrature amplitude modulated signal.

9. The up-converter according to claim 8, wherein the output RF signal is a quadrature amplitude modulated signal.

10. The up-converter according to claim 7, wherein the output RF signal is an analog signal that carries digitally encoded information at a frequency over 1 GHz.

11. The up-converter according to claim 10, wherein the input IF signal is a quadrature amplitude modulated signal.

12. The up-converter according to claim 11, wherein the output RF signal is a quadrature amplitude modulated signal.

13. The up-converter according to claim 1, wherein

said demodulator further comprises

a power splitter to split the received input IF signal into a first split signal and a second split signal,

a first mixer to demodulate the first split signal with an oscillation signal having the same frequency as a carrier frequency in the received IF signal, and to output the result as the real signal component,

a phase shifter to receive the oscillation signal and to shift the frequency 90°, and

a second mixer to demodulate the second split signal with the phase shifted oscillation signal, and to output the result as the imaginary signal component.

14. The up-converter according to claim 13, wherein the first and second mixers are Gilbert cell mixers.

15. The up-converter according to claim 1, wherein

said modulator further comprises

a first mixer to modulate the real signal component with a received oscillation signal having the same frequency as the modulated radio frequency signal,

a phase shifter to receive the oscillation signal and to shift the frequency 90°,

a second mixer to modulate the imaginary signal component with the phase shifted oscillation signal, and

a power combiner to combine the modulated real signal component with the modulated imaginary signal component to produce the modulated radio frequency signal.

16. The up-converter according to claim 15, wherein the first and second mixers are Gilbert cell mixers.

17. An up-converter to up-convert a modulated broadband intermediate frequency signal into a modulated broadband radio frequency signal, comprising:

a demodulator unit to demodulate the broadband intermediate frequency signal into a real signal component and an imaginary signal component;

a reconstruction filter unit to individually attenuate high order frequencies from each of the real signal component and the imaginary signal component, to produce an attenuated real signal component and an attenuated imaginary signal component; and

a modulator unit to modulate the attenuated real signal component and the attenuated imaginary signal component into a modulated broadband radio frequency signal.

18. The up-converter according to claim 17, wherein

said demodulator further comprises

a power splitter to split the received input IF signal into a first split signal and a second split signal,

a first mixer to demodulate the first split signal with an oscillation signal having the same frequency as a carrier frequency in the received IF signal, and to output the result as the real signal component,

a phase shifter to receive the oscillation signal and to shift the frequency 90°, and

a second mixer to demodulate the second split signal with the phase shifted oscillation signal, and to output the result as the imaginary signal component.

19. The up-converter according to claim 17, wherein

said modulator further comprises

a first mixer to modulate the real signal component with a received oscillation signal having the same frequency as the modulated radio frequency signal,

a phase shifter to receive the oscillation signal and to shift the frequency 90°,

a second mixer to modulate the imaginary signal component with the phase shifted oscillation signal, and

a power combiner to combine the modulated real signal component with the modulated imaginary signal component to produce the modulated radio frequency signal.

20. The up-converter according to claim 17, wherein said reconstruction filter unit further comprises a pair of amplifiers to respectively amplify each of the real signal component and the imaginary signal component prior to the respective high frequency attenuation.

21. A method of up-converting a modulated broadband intermediate frequency signal into a modulated broadband radio frequency signal, comprising:

demodulating the broadband intermediate frequency signal into a real signal component and an imaginary signal component; and

modulating the real signal component and the imaginary signal component into a modulated broadband radio frequency signal.

22. The method of up-converting according to claim 21, further comprising:

after the demodulating, individually attenuating high order frequencies from each of the real signal component and the imaginary signal component prior to said modulating.

23. The method of up-converting according to claim 22, further comprising:

respectively amplifying each of the real signal component and the imaginary signal component prior to the individual high frequency attenuation.

24. The method of up-converting according to claim 21, wherein

said demodulating further comprises

splitting the received input intermediate frequency signal into a first split signal and a second split signal,

demodulating the first split signal with an oscillation signal having the same frequency as a carrier frequency in the received intermediate frequency signal, and outputting the result as the real signal component,

shifting the second split signal by 90°, and

demodulating the shifted second split signal with the phase shifted oscillation signal.

25. The method of up-converting according to claim 21, wherein

said modulating further comprises

modulating the real signal component with a received oscillation signal having the same frequency as the modulated radio frequency signal,

shifting the received oscillation signal by 90°,

modulating the imaginary signal component with the phase shifted oscillation signal, and

combining the modulated real signal component with the modulated imaginary signal component to produce the modulated radio frequency signal.

26. An up-converter to up-convert a modulated broadband intermediate frequency signal into a modulated broadband radio frequency signal, comprising:

means for demodulating the broadband intermediate frequency signal into a real signal component and an imaginary signal component; and

means for modulating the attenuated real signal component and the attenuated imaginary signal component into a modulated broadband radio frequency signal.

27. The up-converter according to claim 26, further comprising:

means for individually attenuating high order frequencies from each of the real signal component and the imaginary signal component prior to the modulating.

28. An up-converter to up-convert a modulated broadband intermediate frequency signal into a modulated broadband radio frequency signal, said up-converter being comprised of a plurality of integrated circuits disposed on a single circuit board, said up-converter comprising:

a power splitter to split the received input IF signal into a first split signal and a second split signal;

a first mixer to demodulate the first split signal with a demodulation oscillation signal having the same frequency as a carrier frequency in the received IF signal, and to output the result as a real signal component;

a phase shifter to receive the demodulation oscillation signal and to shift the frequency 90°;

a second mixer to demodulate the second split signal with the phase shifted demodulation oscillation signal, and to output the result as the imaginary signal component;

a reconstruction filter unit to individually attenuate high order frequencies from each of the real signal component and the imaginary signal component, to produce an attenuated real signal component and an attenuated imaginary signal component;

a third mixer to modulate the attenuated real signal component with a received modulation oscillation signal having the same frequency as the modulated radio frequency signal;

a phase shifter to receive the modulation oscillation signal and to shift the frequency 90°;

a fourth mixer to modulate the attenuated imaginary signal component with the phase shifted modulation oscillation signal; and

a power combiner to combine the modulated real signal component with the modulated imaginary signal component to produce the modulated radio frequency signal.

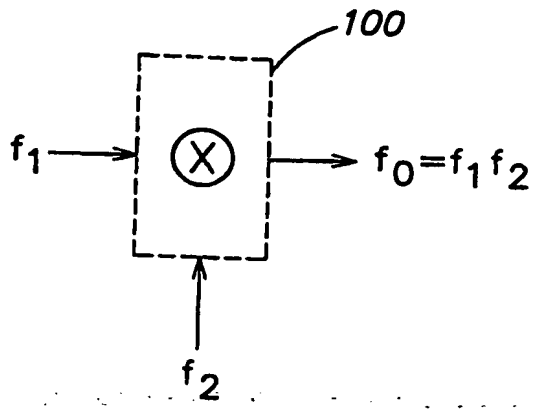


FIG. 1
(PRIOR ART)

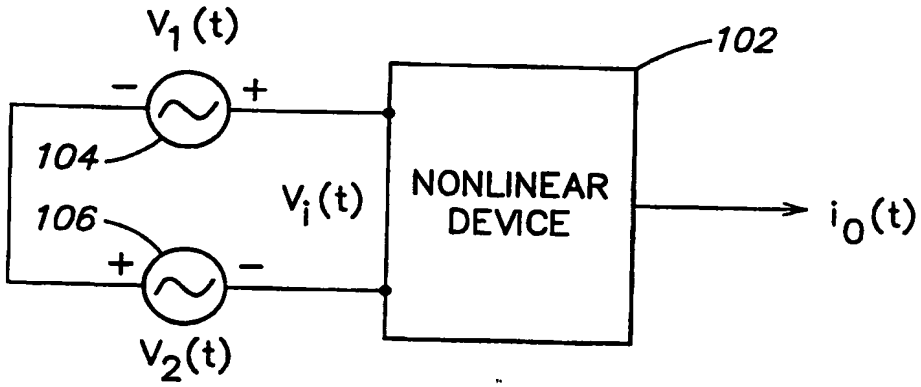


FIG. 2
(PRIOR ART)

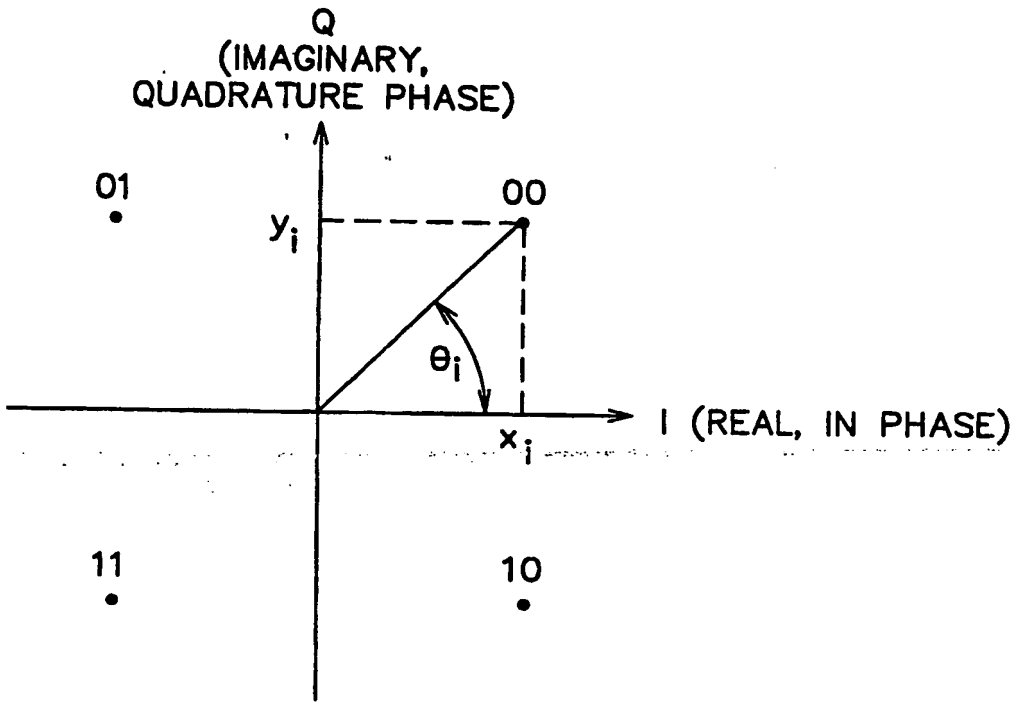

Q
(IMAGINARY,
QUADRATURE PHASE)
01
00
y_i
θ_i
I (REAL, IN PHASE)
x_i
11
10

FIG. 3

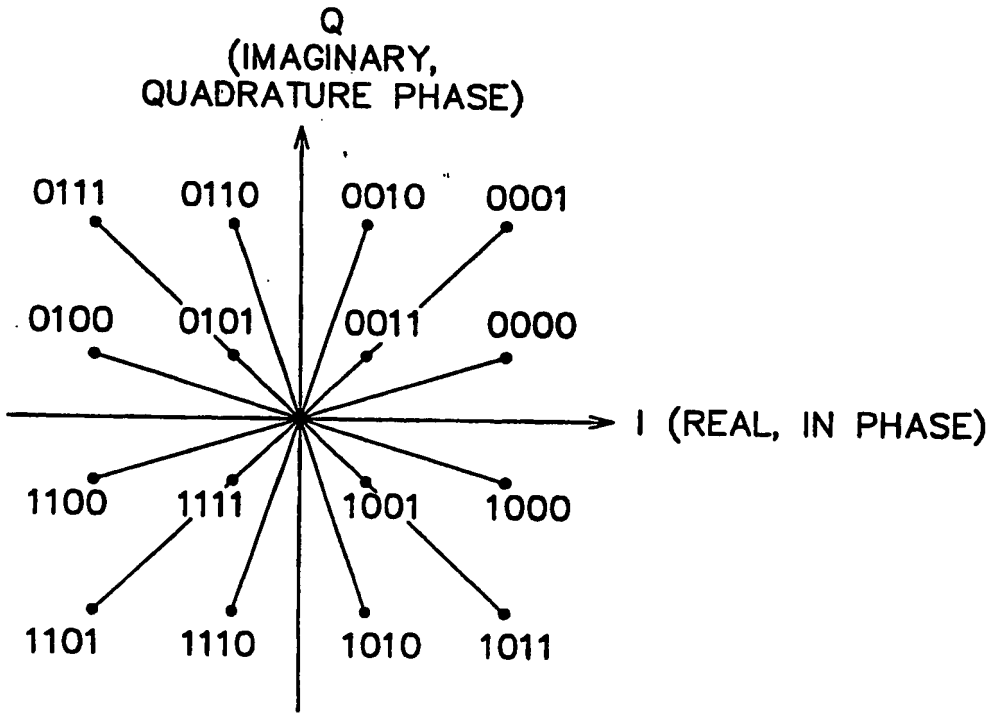

Q
(IMAGINARY,
QUADRATURE PHASE)
0111
0110
0010
0001
0100
0101
0011
0000
I (REAL, IN PHASE)
1100
1111
1001
1000
1101
1110
1010
1011

FIG. 4

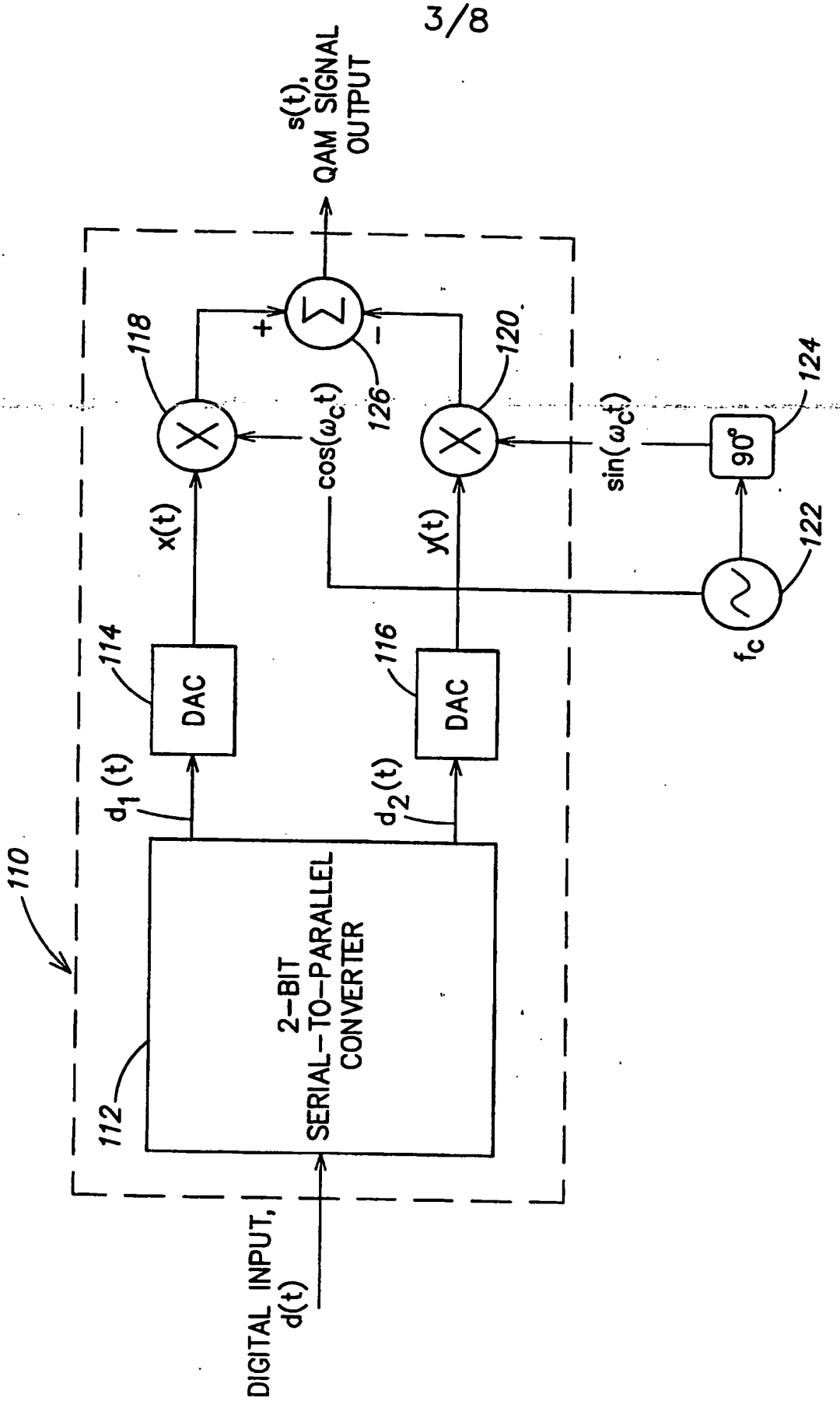

s(t),
QAM SIGNAL
OUTPUT
+
−
118
120
126
124
cos(ωct)
sin(ωct)
90°
x(t)
y(t)
122
fc
114
116
DAC
DAC
d1(t)
d2(t)
110
2-BIT
SERIAL-TO-PARALLEL
CONVERTER
112
DIGITAL INPUT,
d(t)

FIG. 5

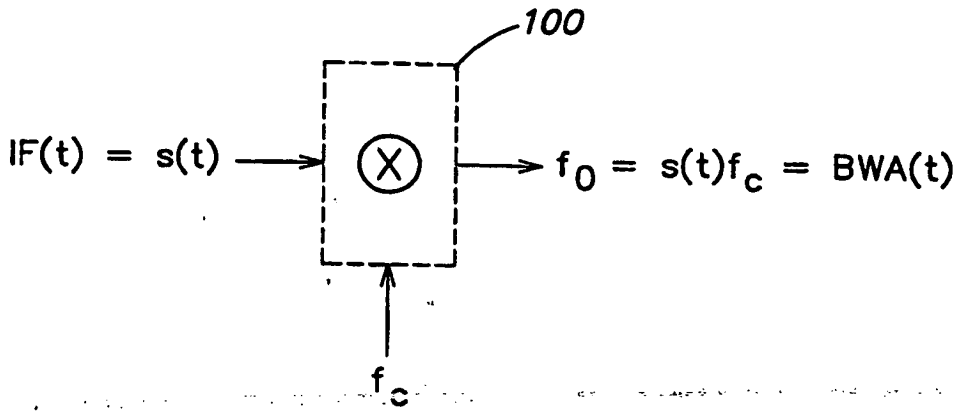


FIG. 6a
(PRIOR ART)

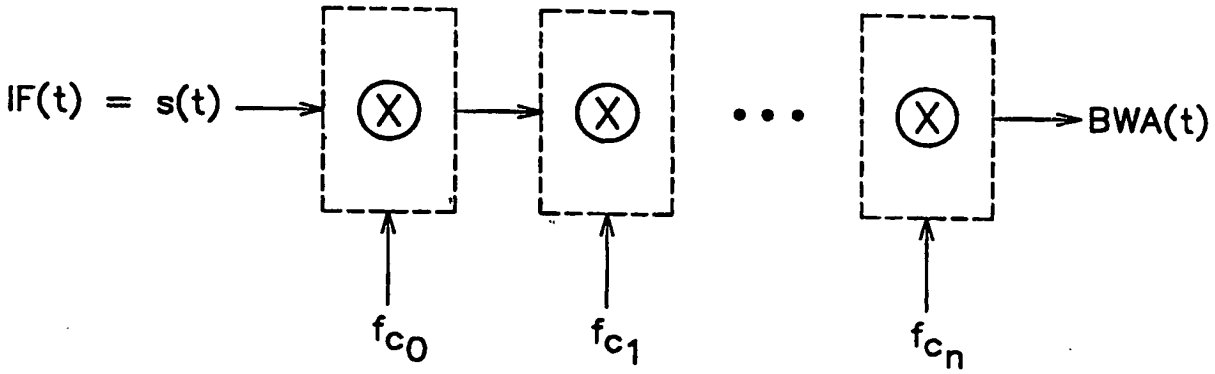


FIG. 6b
(PRIOR ART)

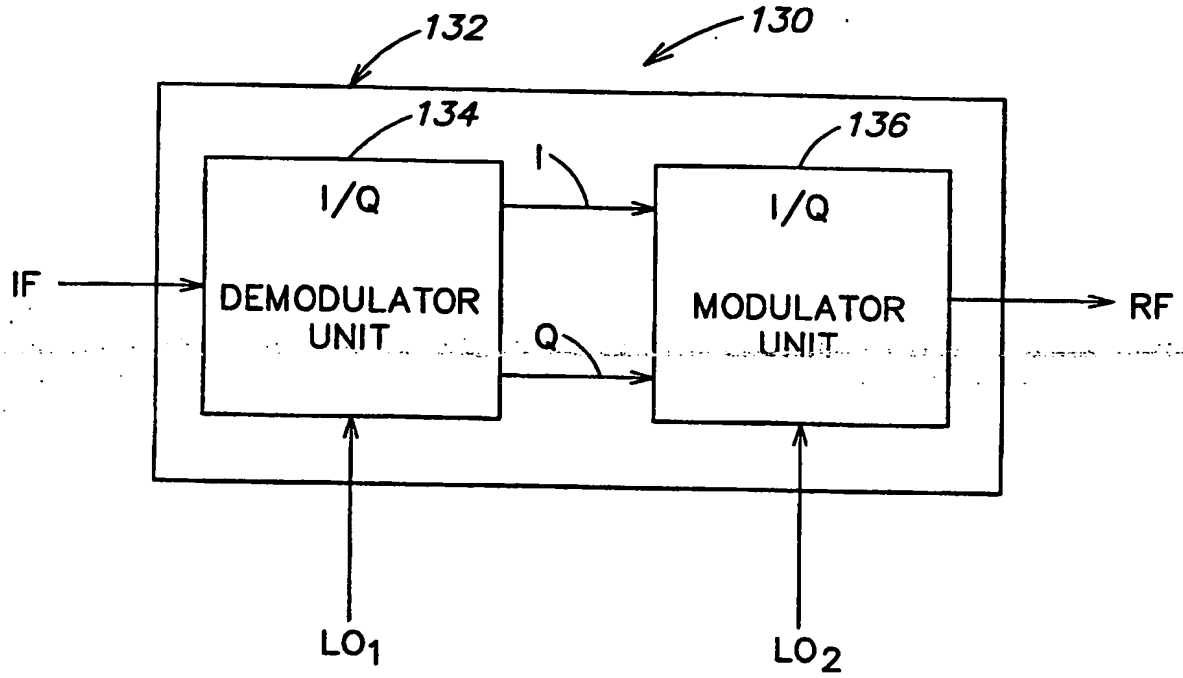

132
130
134
136
I/Q
DEMODULATOR UNIT
I
Q
I/Q
MODULATOR UNIT
IF
RF
LO1
LO2

FIG. 7

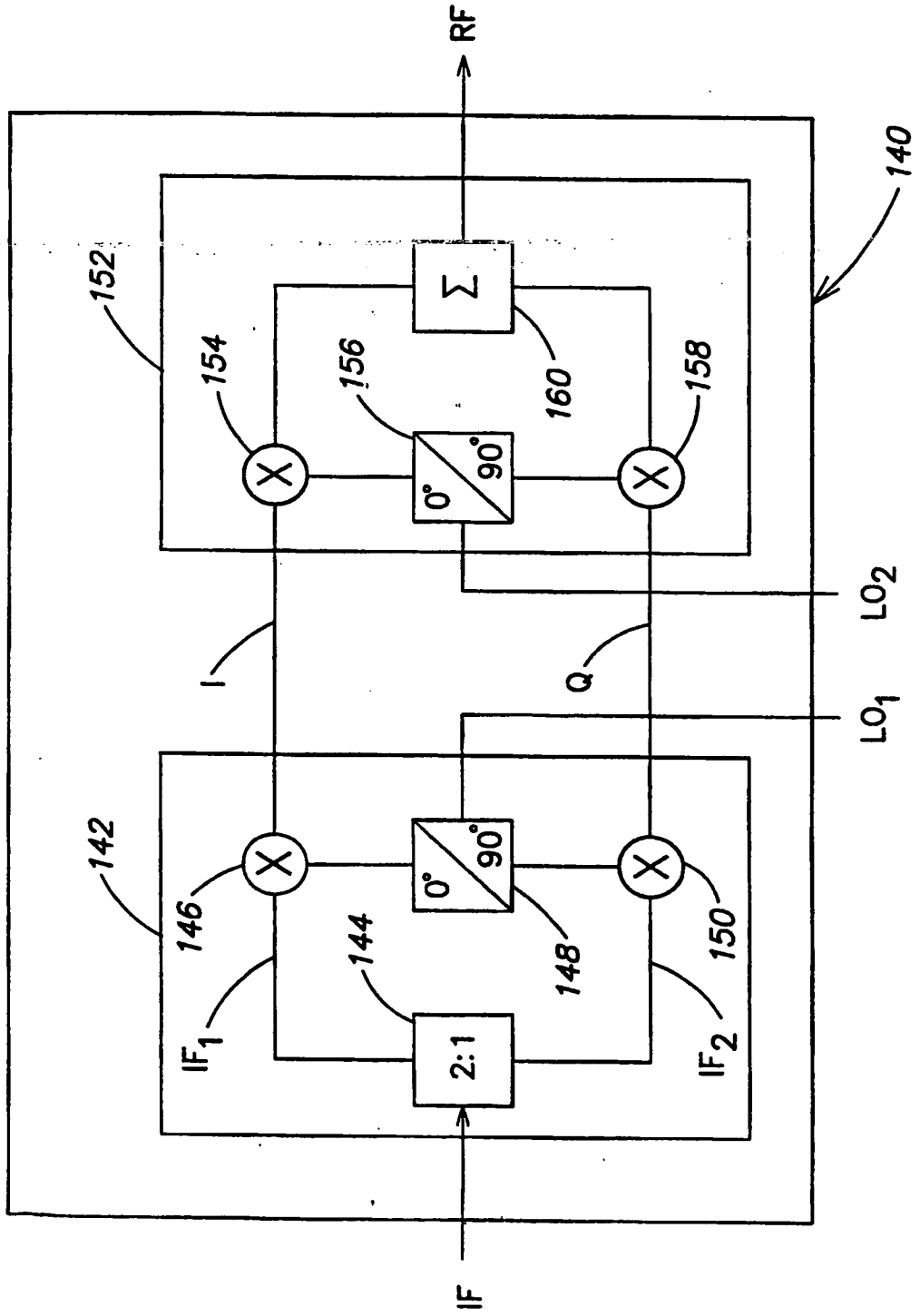

RF
140
152
154
156
160
158
Σ
0°
90°
LO2
I
Q
LO1
142
146
144
148
150
IF1
IF2
2:1
IF

FIG. 8

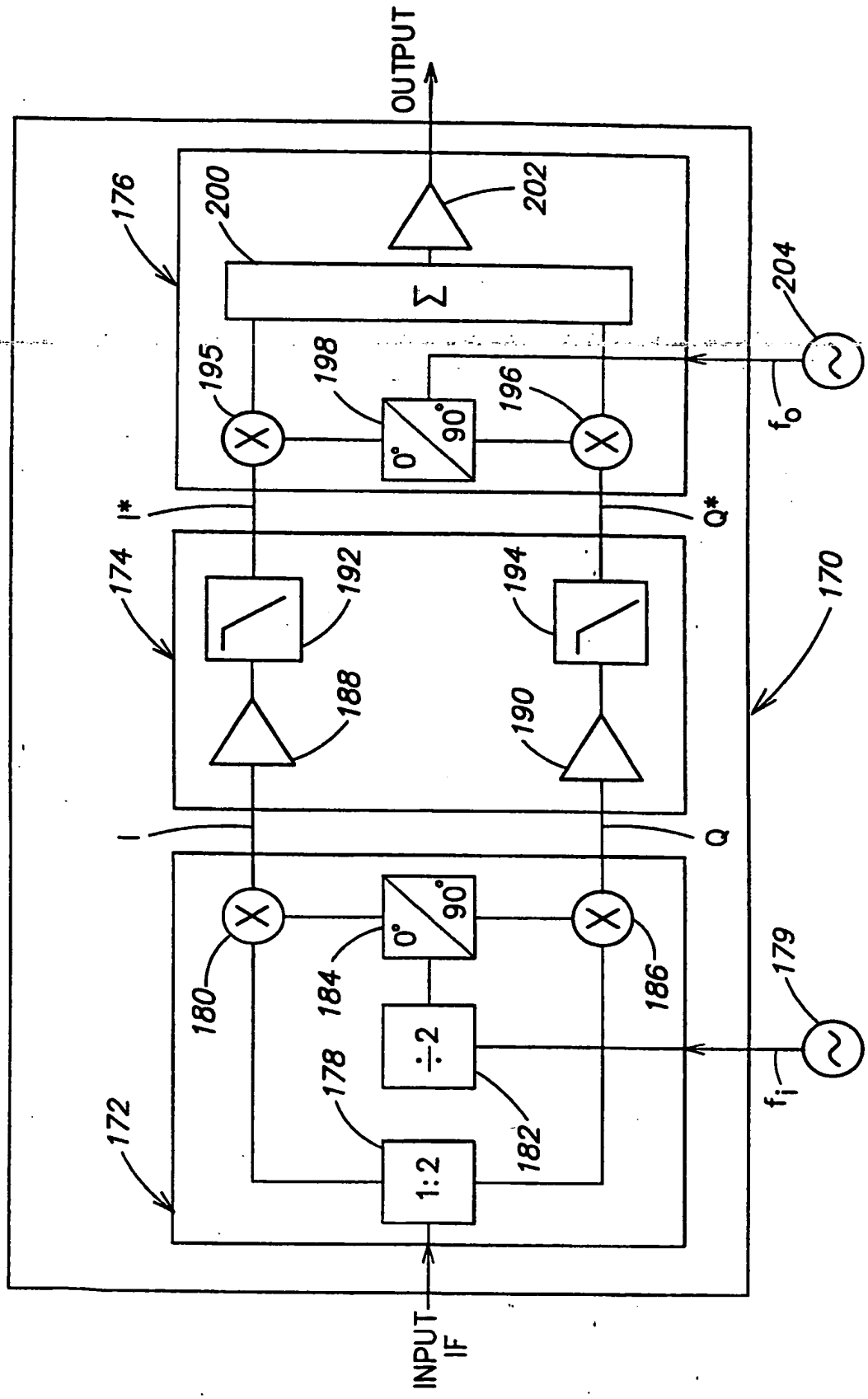

OUTPUT
INPUT IF
176
200
202
Σ
204
f_o
195
198
196
0°
90°
I*
Q*
174
192
194
170
188
190
I
Q
180
184
186
179
f_i
178
÷2
182
172
1:2

FIG. 9

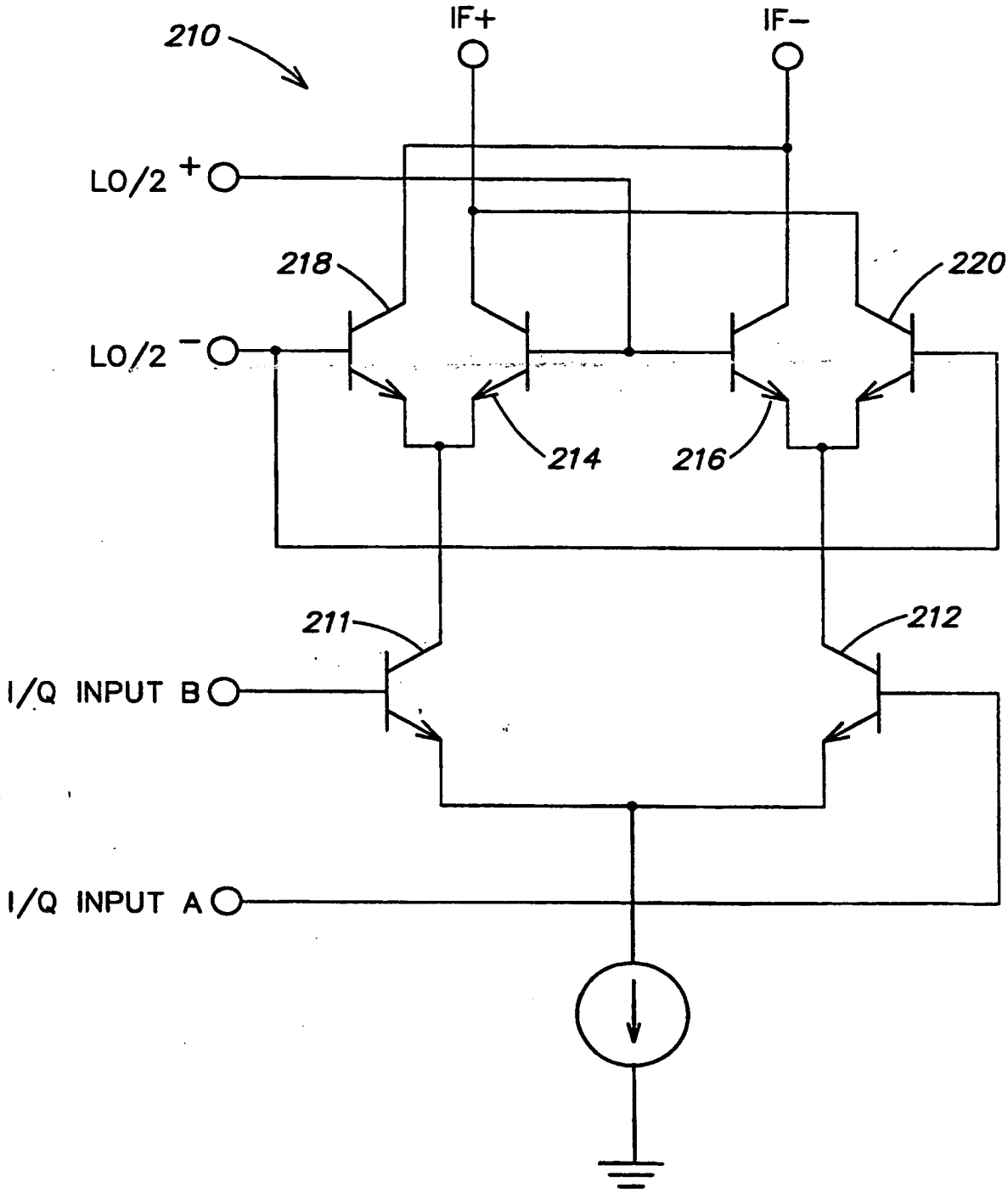


FIG. 10